Computerized tomography of cranial sutures

Part 1: Comparison of suture anatomy in children and adults


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Knowledge of normal suture anatomy and development is vital in order to understand abnormal suture development and to be able to distinguish sutures radiographically from normal anatomical structures and possible skull fractures. The anatomy of the sutures and synchondroses of 150 normal pediatric and adult patients was studied using high-resolution computerized tomography scanning. Sutures of both the calvaria and skull base were most accurately identified in axial and coronal high-resolution thin-section scans when bone window algorithms were used. Developmental changes of the sutures and synchondroses, the inner and outer tables, and the diploic space were all well delineated. Vault sutures could be identified routinely in children, but their presence in adults varied considerably. With increasing age, parasutural sclerosis developed and sutures were more closely apposed.

KEY WORDS • cranial suture • synchondrosis • calvaria • skull base • computerized tomography

PLAIN skull radiographs and radionuclide scans have been the traditional means used to image the sutures of the cranial base and vault. However, neither method can provide adequate images of sutures of the cranial base. Computerized tomography (CT) scanning with high-resolution bone definition algorithms provides a method with which the anatomy of sutures can be examined in detail section by section. For this purpose, CT scans are superior to plain skull radiographs.1,3 The CT appearance of the structure of normal sutures has not been described. In pediatric patients, knowledge of this anatomy is especially important to define the presence or absence of a sutural abnormality, to understand the mechanism of premature closure of sutures and the abnormal growth of the skull that can be caused by these abnormalities, and to avoid confusing a normal suture structure with a fracture on CT scans or plain radiographs.

In this paper, we present the normal anatomy of the cranial base and vault, and the most appropriate techniques for imaging the cranial sutures and synchondroses with CT. Normal variations and changes in appearance of sutures that occur with increasing age are also reported.

Clinical Material and Methods

Axial and coronal high-resolution CT scans for 150 normal patients ranging in age from birth to 74 years, 50 of whom were less than 10 years of age, were reviewed. Patients were scanned as part of a diagnostic procedure for suspected neurological disease or for screening purposes, and scans were reviewed retrospectively. Scans were taken in sections of either 1.5, 5, or 10 mm on either a GE 8800 or GE 9800 scanner. Data were processed using both soft-tissue and bone algorithms and displayed at wide windows. Data recorded included the appearance and ease of visualization of the sutures with either algorithm at wide windows and with increasing age, the relative detectability based on slice thickness, and the scan position in which a particular suture(s) could be best identified. In addition, the relationships and differences in appearance of synchondroses, sutures, and calvarial vascular channels were examined.

Sutures could be more satisfactorily identified in 1.5-mm sections than in thicker 5- or 10-mm sections (Fig. 1). Low scan technique factors (100 mA, 120 kV) were satisfactory for displaying osseous detail on thin sec-
FIG. 1. Computerized tomography scans in a 12-year-old girl. Left: Note the details of all sutures on this 1.5-mm section. The metopic suture is still visible and the coronal, squamosal, and lambdoid sutures can be seen clearly. Right: Same position as left, but the section is 10 mm thick. The metopic suture is visible because this suture is nearly vertical to the axial cut. The lambdoid suture can be seen less well, and the coronal and squamosal sutures are not visible.

Anatomical Description

Appearance of Sutures in Children

Sutures were more easily identified in children than in adults (Figs. 2, 3, and 4). In neonates and young children, sutures were wide with smoothly tapered edges and poorly defined cortical margins. With increasing age, cortical margins became more precise and the space between adjacent membranous bone plates diminished. Finally, by the third and fourth decades, sutures became interlocked. In children, coronal, lambdoid, sagittal, and squamosal sutures could be identified with ease, and mendoval sutures could be identified up to several weeks after birth; metopic sutures could be identified until the 3rd year of life, at which time they usually became completely obliterated. However, the metopic suture is known to persist throughout life in about 10% of adults. Sutures inferior to the vault, including the frontozygomatic, sphenozygomatic, and sphenosquamosal sutures, were also visible (Figs. 2 lower left and 3 left). These suture lines disappeared as early as the second decade in some subjects, but were still visible in the fifth and sixth decades in others. Only rarely could the frontosphenoid suture be identified after the second decade.

Synchondrosis

Sphenopetrosal, petro-occipital, anterior and posterior intraoccipital, and spheno-occipital synchondroses were...
FIG. 3. Computerized tomography scans of regions of the neonate skull. Left: The sphenozygomatic suture can be seen between the zygomatic bone and the greater wing of the sphenoid bone, and is more inferior than the frontozygomatic and frontosphenoid sutures. The sphenosquamosal suture starts from the angular spine of the sphenoid bone, which is immediately lateral to the foramen spinosum, and continues superiority to become the squamosal suture. Center: Section corresponding to the axial cut through the suture line in Fig. 2 lower left, showing the metopic suture, frontosphenoidal sutures, sphenoid (anterolateral) fontanel, squamosal suture, and lambdoid suture. Right: Section 10 mm below that shown center. The occipitomastoid suture can be seen. On the axial view, the occipitomastoid suture is sometimes mistaken for, or is hard to differentiate from, the lambdoid suture, because the occipitomastoid suture is continuous with the lambdoid suture (see Fig. 2 lower left).

could be identified on scans made through the base of the skull (Fig. 5). They also progressively diminished in width and age and ultimately disappeared. The anterior and posterior intraoccipital synchondroses fused in early childhood, and the spheno-occipital in puberty or postpuberty, but the petro-occipital and sphenopetrosal synchondroses persisted into adulthood. Synchondroses could be visualized simultaneously in single 10-mm sections, but 1.5-mm sections through an individual synchondrosis produced the best detail. Because the plane of most of the synchondroses was oblique to that of the axial scan, images of their bone margins were often not sharp.

FIG. 4. Computerized tomography scan of the sagittal suture in the neonate. This suture is seen as a midline single lucency above the lambdoid sutures posteriorly, and above the anterior fontanel anteriorly.

Appearance of Sutures in Adults

The ability to identify sutures in adults varied considerably. Sutures were completely closed as early as the second or third decade, but in some adults suture lines persisted beyond the seventh decade. Parasutural mineralization was frequently identified if the suture line was still visible, but when the suture was absent, either a single linear area of bone mineralization could be seen, or there was no evidence that a suture had been present (Fig. 6).

Although the ability to identify sutures in adults varied considerably, there was a definite tendency for bony fusion to progress with increasing age. These observations confirm the classic description of Todd and Lyon, who, on the basis of postmortem studies, observed that the rate of fusion of sagittal, coronal, and lambdoid sutures was maximum by the third decade and that sutures continued to fuse through and after the sixth decade.

Diploic Space

In neonates, the diploic space was poorly developed (Fig. 3 center and right). During the first 2 years, the inner and outer tables, diploic spaces, diploic veins, and vascular markings and grooves for the dural sinuses on the internal surface of the calvaria all appeared. The diploic space was fully developed in adults. Comparison of the appearance of the skull vault from childhood to old age is shown in Fig. 6. Occasionally, venous channels in adults were difficult to distinguish from sutures, especially in the axial view (Fig. 6G). On occasion they had the same symmetry as sutures; venous channels rarely had an adjacent increase in bone mineralization.  

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FIG. 5. Computerized tomography scan (left) and diagram of scan (right) in a 3-month-old boy. Compare to Fig. 2 lower left. The spheno-occipital, anterior and posterior intraoccipital, petro-occipital, and sphenopetrosal synchondroses can be seen. The sphenosquamosal suture is also apparent on this section.

FIG. 6. Computerized tomography scans of patients of increasing age. A: A 2-year-old boy. The inner and outer tables and diploic space can now be clearly differentiated. Compare with Fig. 3 center and right. B: A 12-year-old girl. Sphenosquamosal and occipitomastoid sutures are seen on this cut. The spheno-occipital synchondrosis is still visible. The sutures and cranial vault are well advanced toward maturity, and quite close in appearance to the structure seen in adults. C: A 46-year-old woman. The frontosphenoidal, sphenosquamosal, squamosal, and lambdoid sutures are seen as very thin lines or sclerotic areas adjacent to the sutures. Note the thinning of the occipital and parietal bones at and adjacent to the lambdoid sutures. D: A 54-year-old man. The coronal sutures on both sides and the sagittal suture can be seen as single linear lucent zones extending through the inner and outer tables. Note the bone mineralization adjacent to these zones. E: Same patient as in D. The bone mineralization is more prominent in this upper section. F: A 68-year-old woman. Both coronal sutures can be seen as focally sclerotic areas. The sagittal suture is completely obliterated. G: A 74-year-old man. The coronal sutures and sagittal suture are clearly defined as serrated linear lucent zones with prominent adjacent bone mineralization. The linear structure posterior to the coronal suture on the left side is a diploic vein, around which there is no bone mineralization.
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FIG. 7. Computerized tomography scans in a 74-year-old woman. Left: The bilateral bregmatic veins are situated rather symmetrically immediately posterior to the coronal sutures, but there is no increase in bone mineralization adjacent to the veins. Right: Lateral scout view confirming the presence and site of the prominent bregmatic diploic veins.

FIG. 9. Photomicrograph of a normal suture (S). The calvarial bones are composed of dense lamellar bone. The borders are well defined, and only small areas of remodeling and new bone growth are present (arrow). The suture space(s) consists of vascular dense fibrous connective tissue. This sample was taken from a lambdoid suture with no synostosis in a 2-month-old boy. H & E, × 47.

and rarely traversed both tables of the skull vault. If sutures could not be delineated clearly, correlation with a projection radiograph (scout view) or with a plain skull radiograph was helpful (Fig. 7).

Differentiation from Fracture

It may often be difficult to distinguish sutures from fractures on CT scans. Fracture lines usually have sharp margins, no adjacent sclerosis or bone thinning, and no serrations or bone fragment displacement. However, knowledge of the appearance and position of the normal sutures is the most important factor in distinguishing between a suture and a fracture (Fig. 8).

Suture Histology

The normal patent sutures examined histologically in this study were all obtained from children and were all examples of syndesmoses. The adjoining calvarial bones in each instance were composed of typical mature lamellar bone with smooth margins enclosing nonossified regions containing bone marrow and vascular channels (Fig. 9). A rim of prominent osteoblasts usually was present in the periosteum of the calvarial bones. Occasionally present were small foci of new bone formation or remodeling characterized by focal aggregation of osteoblasts with production of woven bone (Fig. 9). These foci differed from the prominent bone growth seen in some craniosynostoses by the absence of significant bone encroachment into the suture space, and the absence of prominent spicules of new bone growth at the calvarial bone margins. The normal suture space was filled by well vascularized dense fibrous connective tissue. A series of distinct layers within this fibrous tissue, which in turn can be correlated with specific functional zones of active growth, have been described, we could not identify such areas in our examination of material stained with hematoxylin and eosin. No normal synchondroses were examined histologically.
Discussion

The sutures of both the calvaria and the skull base are most accurately identified on axial and coronal high-resolution CT scans. In general, 1.5-mm thick sections provided better detail than 5- or 10-mm sections in identifying sutures. Although the thin-section technique requires that more cuts be made compared with the thicker-cut technique, the use of very low x-ray levels expedites the examination. Additionally, the use of thin sections permits three-dimensional reconstruction of pre- and postoperative CT scans, which allows evaluation of surface contours of the facial structures and cranium. Scans perpendicular to the plane in which the suture lies are most appropriate. The axial plane is therefore appropriate for all sutures of the cranial vault with the exception of the sagittal suture, for which the coronal scan is better suited. Sutures are best viewed at maximum window widths in adults. Because mineralization in children is minimal, a narrow window (1200 H) is appropriate.

Compared with other techniques, the CT scan is a most useful technique for delineating the developmental changes that occur with increasing age in the sutures and synchondroses, and for delineating alterations in the inner and outer tables and the diploic space. The visibility of sutures in adults varies considerably, but sutures may be identified into the seventh decade. With increasing age, however, there is closer apposition of the sutures and the development of parasutural sclerosis. Vascular channels can usually be distinguished if the anatomy of sutures is known, if there is no involvement of both the inner and outer tables, and if there is the usual lack of symmetry. In rare instances, a skull radiograph may be required to distinguish between a suture and a venous channel. Knowledge of the anatomy of normal sutures is of importance if abnormal suture development is to be understood, and is necessary to distinguish between normal sutures and fracture lines.

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References


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